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Improving a conventional greenhouse solar still using sun tracking system to increase clean water yield

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ABSTRACT

In this paper the performance of active sustainable solar still was studied. A conventional greenhouse solar still coupled with a flat-plate solar collector and photovoltaic (PV) system was built and tested. The sun tracking system was designed for the solar collector to track the sun position and to heat up the water flowing through the collector. This helps to further increase the water temperature in solar still basin and increase the daily yield of distilled water. The system consists of a solar still, a flat-plate collector, and a PV module to provide power supply to all the electrical components in the control system. Two-axis tracking was built to control the direction of the solar collector. The system was tested in Kuching (01°33′ N, 110°25′ E), (Sarawak, Malaysia) in different weather conditions. The obtained results show that there is a significant growth in the experimental thermal efficiency of the active solar still with sun-tracking (38.55%) as compared to the passive one (22.70%). Its efficiency is even higher as compared to active the non-sun-tracking solar stills (34.70%). This proves that solar collector with sun-tracking can indeed improve the performance of a solar still. In addition there is a small increase of 3.98% in the still efficiency for active solar still with sun-tracking (38.55%) as compared to the non-sun-tracking (34.70%). Comparisons between theoretical and experimental results are also presented.

Keywords: Solar Still; Desalination; Solar collector; Sun-tracking system; Photovoltaic cell; Water yield

1. Introduction

Clean water supply has become an essential issue as 40% of the world's population will face a shortage of an adequate fresh water supply by year 2015 [1]. It is forecasted that the percentage will increased to 67% by year 2025 [2]. Among every means to produce fresh drinkable water, solar distillation is perhaps the most prominent method in areas endowed with long sunshine hours as simple technology with low maintenance is required.

Solar distillation has long been used in the history of mankind. Early 2000 years ago, this technology was utilized to produce salt rather than drinking water. In 4th century B.C. Aristotle described a method to evaporate impure water and then condense it for potable use. Nonetheless, documented used of solar stills began in the sixteenth century, by Arab Alchemists [3]. The first conventional solar still of 4700 m^2 basin area was built in 1872 at Las Salinas in Chile by Swedish engineer Charles Wilson, to supply drinking water for a mining

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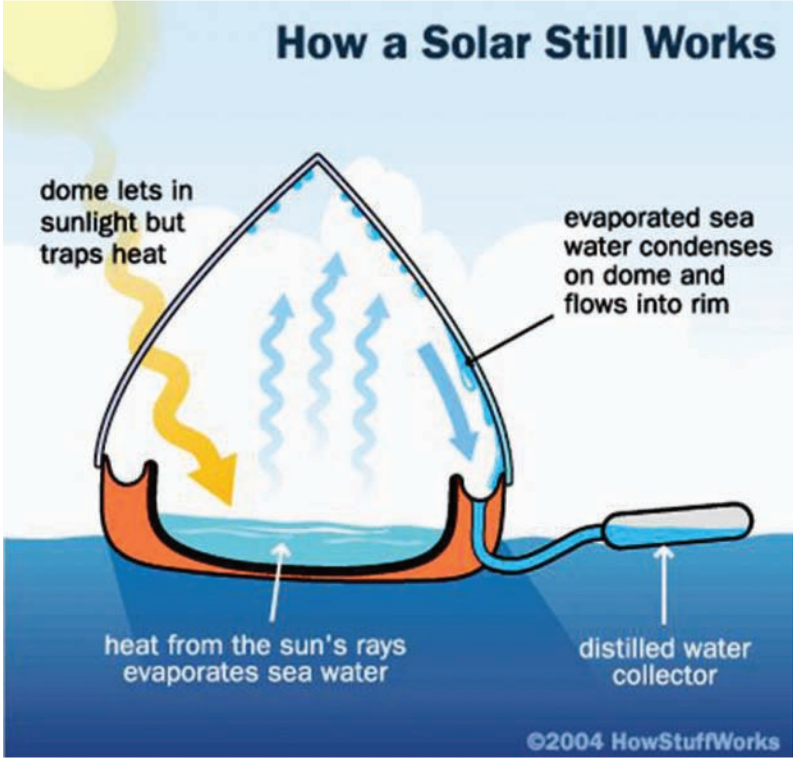

Fig. 1. How a solar still works, [7].

community [4]. During the Second World War, 200,000 inflatable plastic stills were put in life-crafts for the US Navy. This is the first mass production of solar water distillation (Solar Distillation).

Mimicking the way of how Nature produces rain, solar distillation is a process to distil brackish/saline water by utilizing solar energy. The distillation output of a solar still mainly depends on the difference between water and glass cover temperatures, solar radiation received to basin, area of condensing cover, ambient temperature, and air velocities [5], utilizing Green House Effect inside the still. The air just above the water surface will be saturated with water vapour corresponding to the water temperature [6]. This is caused by the existence of phase equilibrium between the saline water surface and air space. With the solar radiation incident on the saline water, the saturated water vapour pressure near the water surface will be increased as its surface temperature increases. As the temperature of the inner surface of the glass cover is lower than that of the water surface, the partial pressure of water vapour near the glass surface will be less, and the difference in partial pressures of water vapour will cause the transfer of water vapour from the basin water surface to glass surface and the condensation on the inner surface of the glass. Fig. 1 illustrates the basic concept of how a solar still works. The rate of evaporation of water vapour from the water surface depends on the rate of condensation of water vapour in the glass cover.

2. Efficiency and productivity of various configurations of solar stills

Many researches have been carried out to enhance the efficiency of the solar still. Amongst the techniques used, researches concentrated on enhancing the productivity of solar still by increasing the temperature inside the solar still by concentrator, sun-tracking system and change the geometry of solar still. The parameters affecting the solar still output were studied [8]. They had dealt with the effect of the following factors like solar intensity, ambient temperature, wind velocity, glass cover angle and depth of saline water on the performance of still. In general, the productivity of the solar still increases as the solar intensity increases. The still productivity for different parameters like depth of saline water, insulation thickness and various cover angles had discussed [9]. The still productivity was approximately 2.5 kg m^{-2} d at 40 mm depth, 3.5 kg m^{-2} d at 50 mm depth and 2.8 kg m^{-2} d at 80 mm depth for maximum solar intensity of 1016 W m^{-2} in the month of July 1996. A sun-tracking system for enhancing the solar still productivity was developed [10]. A computerized sun-tracking

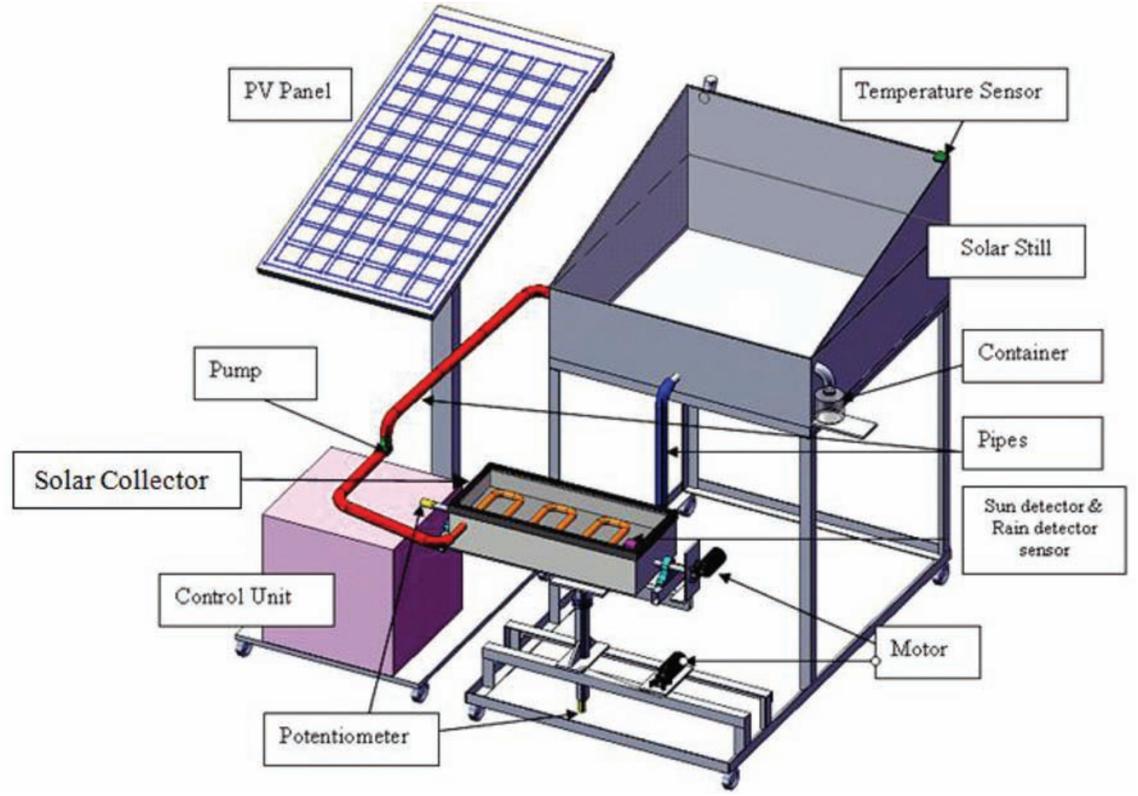

Fig. 2. The proposed system of solar still.

device was used for rotating the solar still with the movement of the sun. A comparison between fixed and sun tracked solar stills showed that the use of sun tracking increased the productivity for around 22%, due to the increase of overall efficiency by 2%. The still productivity of conventional still compared to double-glass cover cooling arrangement was studied [11]. In that study conventional still productivity was 1.4 kg m^{-2} d in the month of March and 3 kg m^{-2} d in June. They had 34% of increase in still productivity. The behavior of a conventional greenhouse type solar still coupled with hot water storage tank is experimentally investigated [12]. The result shows a higher distilled water output and ensures the operation of the system during periods of low or no sunshine due to the continuation of the distillation process in these periods, as a result of the heat transfer from the hotter tank water to the colder basin water. An experimental study was performed to investigate the effect of using two axes sun tracking system on the thermal performance of compound parabolic concentrators (CPC) [13]. The tracking of CPC collector showed a better performance with an increase in the collected energy of up to 75% compared with an identical fixed collector.

The proposed solar distillation system is a hybrid and sustainable system and can work by itself without any monitoring. Also there is a great scope for improvements to increase the efficiency of such type of solar stills. The key objective is to improve the performance of a traditional single slope solar still through the combined functioning of the solar still with solar collector controlled by a sun tracking system to increase the solar collector capability to capture more solar radiations.

3. Experimental setup

The experimental setup shown in Fig. 2 consists of a solar still, flat plate collector, photovoltaic panels, and electric and control components. The effective area of solar still is ($1 \times 1\ m^2$). The whole body of the still is acrylic-fabricated and painted white to reduce its solar absorptivity. On the contrary, the basin is painted black to have the maximum solar absorptivity. The cover of the solar still must transmit solar radiation with minimum amount of absorption and reflection within the solar spectrum. Also, it acts as resistance to thermal radiation heat transfer from the basin to the atmosphere. A transparent acrylic sheet is used as the cover for solar still and is fixed at 15 degrees slop on the top of the inclined still. In the solar collector the absorber plate is made of zinc plate painted black to have the

Table 1
Performance of the PW 1000 series

Typical power	Minimum power ($P_{\min}$)	Voltage @ peak power (V_m)	Current @ peak power (I_m)	Short circuit current (I_{sc})	Open circuit voltage (V_{oc})
105	100.1	34.6 (17.3)	3.05 (6.1)	3.15 (6.3)	43.2 (21.6)
100	95.1	34.4 (17.2)	2.9 (5.8)	3.0 (6.0)	43.2 (21.6)
90	85	33.6 (16.8)	2.7 (5.4)	2.8 (5.6)	43 (21.5)

maximum solar absorptivity. The body of collector is constructed from high-density plywood. Foam materials and cardboards are used as insulating materials. A 3.6 m copper tube was installed inside the body of the collector on the top of foam material. A transparent acrylic sheet is used as glazing to trap the heat. The final dimensions of the flat-plate collector are $0.71 \times 0.30 \times 0.15$ m^3. The collector is mounted on a custom made steel frame, together with the solar still. The PV cell PhotoWatt PW100/UL and battery Cellyte 12TSG 100 Bloc are used to provide the power source in the designed system. The PV cell is fixed on aluminum bars with the inclination angle of 15°. The specification of the PW 1000 series is shown in Table 1. As shown in Fig. 2, rollers are attached to steel structures so that the equipment is easy to be moved from indoor to outdoor for experiment, and vice versa.

3.1. Design of active sun-tracking and power subsystems

The dynamic subsystem in Fig. 2 is designed to satisfy the optimal conditions of solar still operation. The power and control components of the solar still system include:

1. Two 12 V DC motors operated by Cytron MD30A driver and four Light Dependent Resistors (LDR) to track the motion of the sun during the day and provide proper orientation of the flat-plate collector facing straight toward the sun. This will provide optimal condition for the absorption of maximum solar radiation during the day and put the system into the sleep during the night.
2. Customer-made rain sensor to detect the rainy weather condition and if it is triggered the collector will be sent into the default initial position.
3. Two temperature sensors installed one inside the basin space and the other in collector space to monitor their internal temperature conditions as well as to trigger the pump circulating water in closed-loop piping system of the solar still.
4. Stationary 200 micron photovoltaic (PV) solar cells panel PhotoWatt PW/100 UL with regulator to convert sun energy in to the electrical one and Cellyte 12TSG 100 Bloc rechargeable battery to store that energy for the subsequent usage by the pump.
5. 12 V Windshield Washer Pump with relay switch to trigger the pump that circulates water in the solar still system.
6. PIC16F877 microcontroller board to provide the overall logic control of all hardware components of the solar still system.
7. Fig. 3 illustrates the overall components setup for sun-tracking solar still.

3.2. Sun-tracking strategy for optimal absorption of solar radiation

Two pairs of LDR sensors are located on opposite sides of two non-transparent plates as shown in Fig. 4. This arrangement will create shadows on alternative sides of the plates when the sun moves across the plates during the day. As a result the resistance of two LDR sensors will be different right at the beginning of the day time since they will receive different amount of light.

If the LDR sensors form the two arms of the Whetstone Bridge, i.e. R_1 and R_3 (as shown in Fig. 5) then it will create a potential difference V_{DB} across the output terminals of the circuit due to that resistance difference. It is this potential difference that drives motors of the flat-plate collector (tracker rotating) until both resistors will be exposed equally to the sun and the tracker will be in stable state. At this state the plate with collector faces straight toward the sun and receives maximum solar energy. Therefore, this shade casting technique will constantly adjust the orientation of the collector during the day.

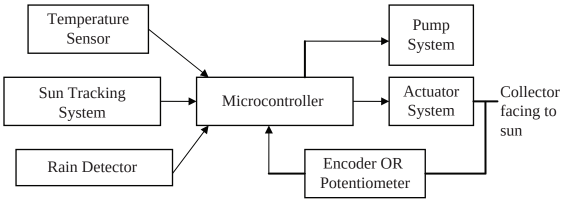

Fig. 3. Overall components setup for sun-tracking solar still.

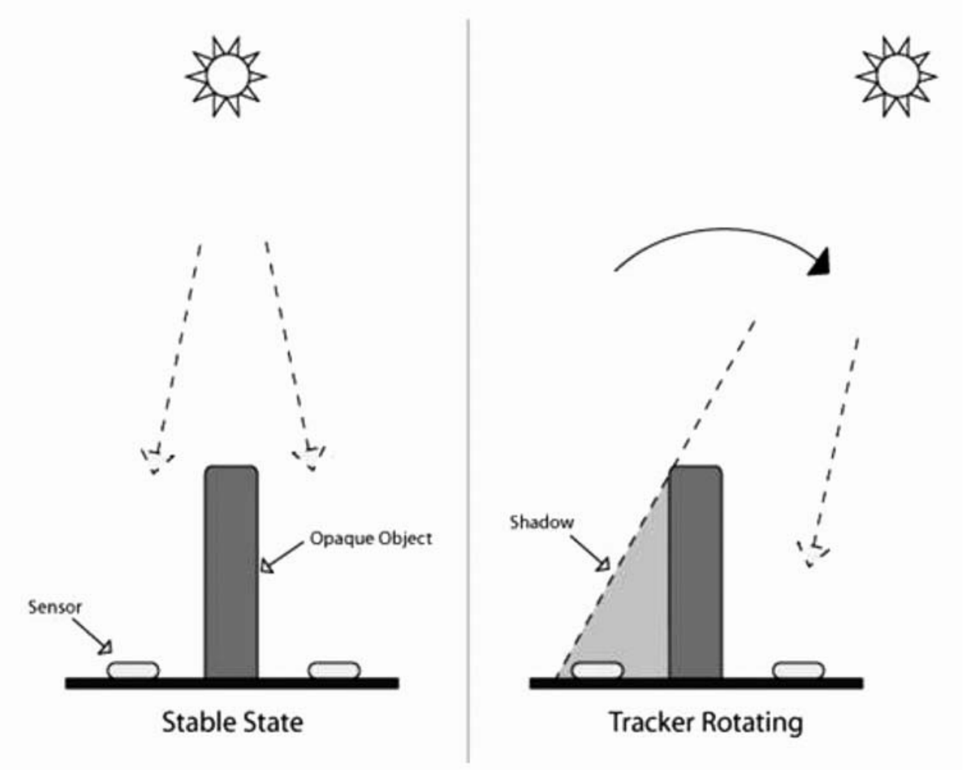

Fig. 4. Shade casting by the plates.

The rain sensor located on the collector (Fig. 2) returns it to initial position in order to protect the circuitry from rain. It consists of two copper strips with gap in between exposed to the environmental conditions. If rain, the water drops would close up the circuit built on these copper conductors as shown in Fig. 6.

3.3. Power subsystem of the solar still

The system Windshield Washer Pump drives the water along the close-loop pipelines through the collector tubes to utilize the additional heat source and to increase the efficiency of water distillation process in the solar still. The energy to drive the pump is supplied from the Cellyte 12TSG 100 Bloc rechargeable battery that is charged autonomously during the day from the stationary PhotoWatt PW/ 100 UL solar panel which employs the well known PV technology. The use of solar cells and the rechargeable battery makes the designed solar still fully autonomous, energy efficient and independent of any external power source.

The pump operates in intermittent cycles to save the energy of the battery. The switching of the pump by means of relay switch depends on the reading of two temperature sensors; one installed inside the basin space and the other in the collector space. The pump is actuated whenever the collector check point temperature exceeds the basin check point temperature and the pump stops when the readings from two sensors become about the same. During the actuation time the pump delivers the hotter water from the collector into the basin thus increasing further the temperature of water inside the basin and efficiency of evaporation.

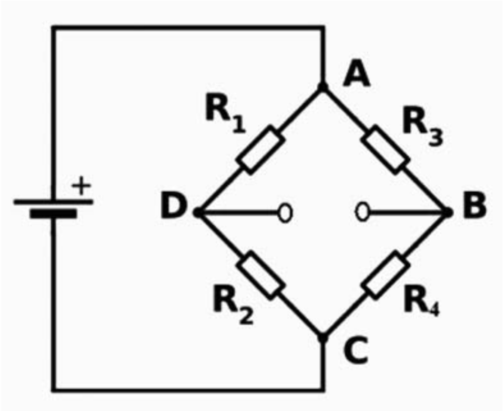

Fig. 5. Whetstone Bridge.

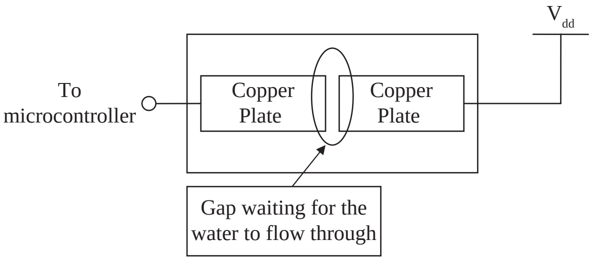

Fig. 6. Rain sensor layouts.

3.4. Solar still controller design

The system logic is presented in Fig. 7. The controller sequentially check the status of the day light sensor to put system on halt during the night, check the status of rain sensor to move the collector to the default position, check the basin and collector temperature sensors to operate the pump, then operates the sun tracking system to put the collector in proper orientation with respect to sun, and finally check the system operation termination button. If the system is not terminated by the user then the controller repeats the checks all over again.

The logic presented in Fig. 7 is implemented using 40-pin PIC16F877 microcontroller with LM7805 5V regulator. Each microcontroller data pin is connected to a 220 ohm resistor in series to limit the current flowing in or out from the microcontroller. The analogue temperature and light sensors are connected to the specified pins (An1 to An6) that have multiplexing and ADC features and the DC motors of the tracker are connected via motor drivers to the specified pins (16 and 17) that provide PWM digital pulses. The port D of the microcontroller is connected to 2×16 LCD to display temperature readings from the sensors. All the codes are written using simplified C language.

3.5. Comparison of the water yield of the solar still in various configurations

Fig. 8 shows the experimental hourly yield of solar still in different conditions, i.e. passive still, active still with and without sun-tracking and theoretical with tracking (Tiwari, 2008). Since there was a single experimental set up of solar still in this work various configurations of solar still were tested at three different days of the November month in Kuching. It is noticeable that active still with sun-tracking not only marks the highest peak yield (at 3 p.m.), but also has the maximum daily yield compared to the others. It is apparent in Fig. 8 that from 8 a.m. to 12 noon the sun energy is being used to heat up the water in the basin. Only when the water temperature in the basin is become higher than the inner temperature of the glass cover of the still, the still starts to supply output water. The increase in hourly yield for passive still after 3.30 is solely due to the raining at that time, causing the outer and inner temperature of the glass to drop drastically (Fig. 9). Otherwise (in case of no rain) the yield should drop like in other configurations due to decrease of solar irradiance.

The pumping of the water into the basin was intermittent and cycles depend on the difference of water temperature in the basin and the water temperature in the collector. The cause contributing to high root mean square deviation in Fig. 8 is due to the unpredictable weather of year-end monsoon season in Malaysia. It should be made clear that for sun-tracking experiment, 16/11/2008 was a cloudier day compared to 9/11/2008 (passive still) and 15/11/2008 (active still without sun-tracking). This explains the small increase of 3.98% in the still efficiency for active solar still with sun-tracking (38.55%) compared to the non-sun-tracking one (34.70%). The major factor affecting the process of condensation on the inner glass surface and as a result the total amount of water yield of solar still was obviously temperature on the inner surface. The wind speed over the outer surface of the glass was not an essential factor for the experiments because it has very low and constant value during the day in Kuching throughout the year. Very little gasp of wind normally occurs for a few minutes time just before the rain starts. Figs. 9–11 show experimental (as read from the built-in temperature sensor) and theoretical temperatures (Tiwari, 2008) for inner glass at different solar still configuration. These graphs are also representative for the air temperature outside of the solar still during the days of experimentations. The apparent root mean square deviation in the figures is caused by the intermittent pumping and altering weather condition.

4. Conclusions

The paper describes design and implementation of a new hybrid active solar still system with solar tracking capabilities. The sun-tracking system has been designed and tested to increase the yield of the still. The following results are obtained:

1. Experiments prove that passive solar still has the lowest thermal efficiency (22.70%).

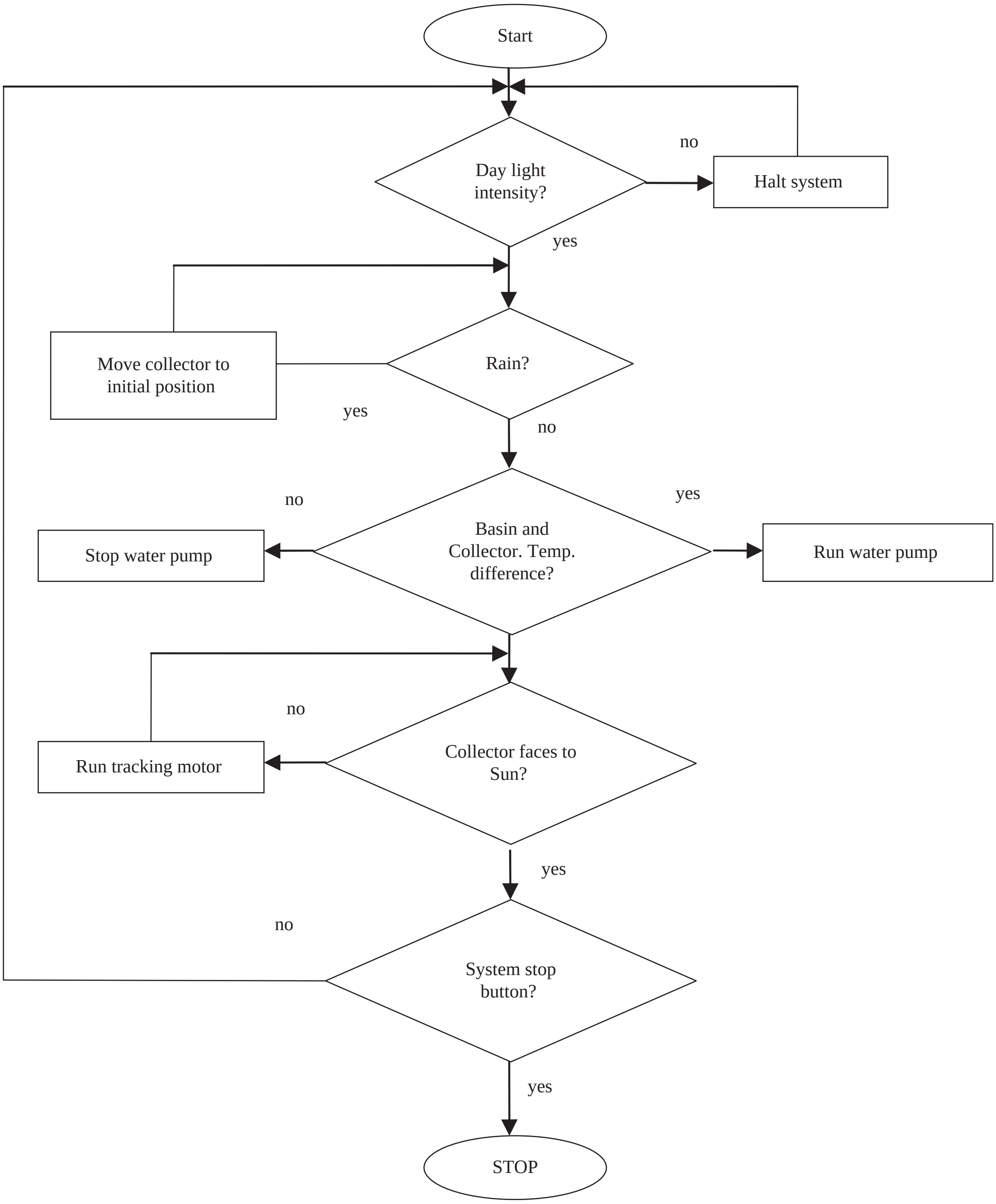

Fig. 7. Operational block diagram of the system.

2. The thermal efficiency of active solar still without sun-tracking (34.70%) is lower as compared to active solar still with sun-tracking (38.55%). This increase was observed for partially clouded days in November monsoons and may rise significantly for sunny days in non-monsoon seasons.
3. Results obtained from experimental work show reasonable agreements with predicted results.

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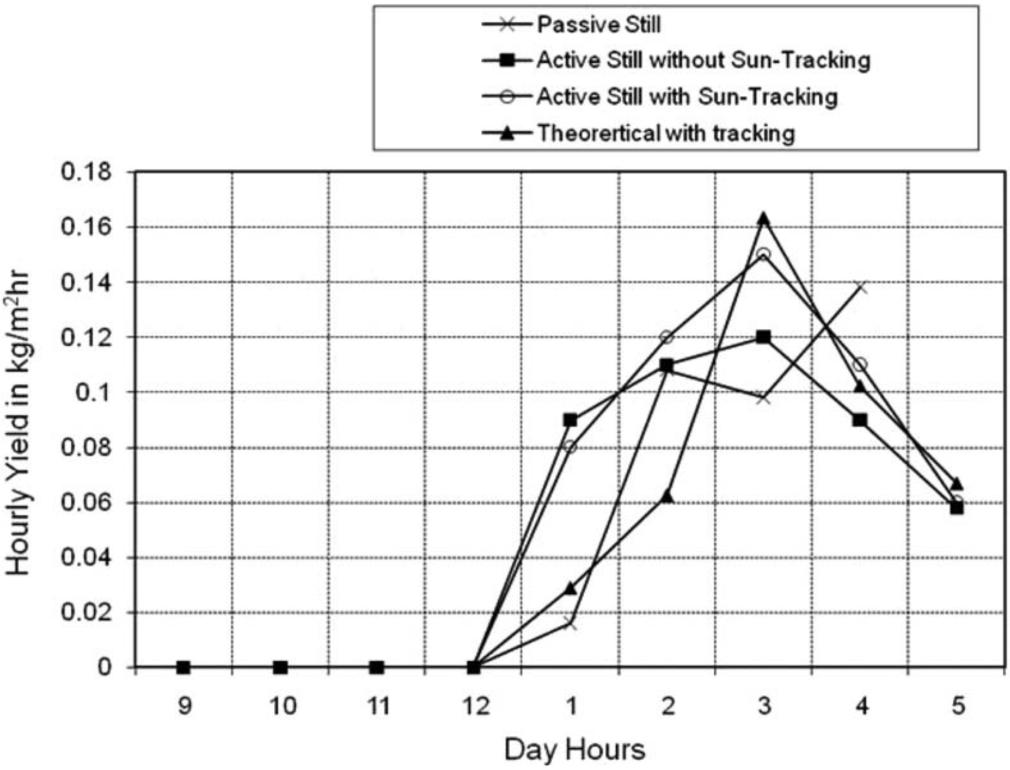

Fig. 8. Hourly yield of solar still.

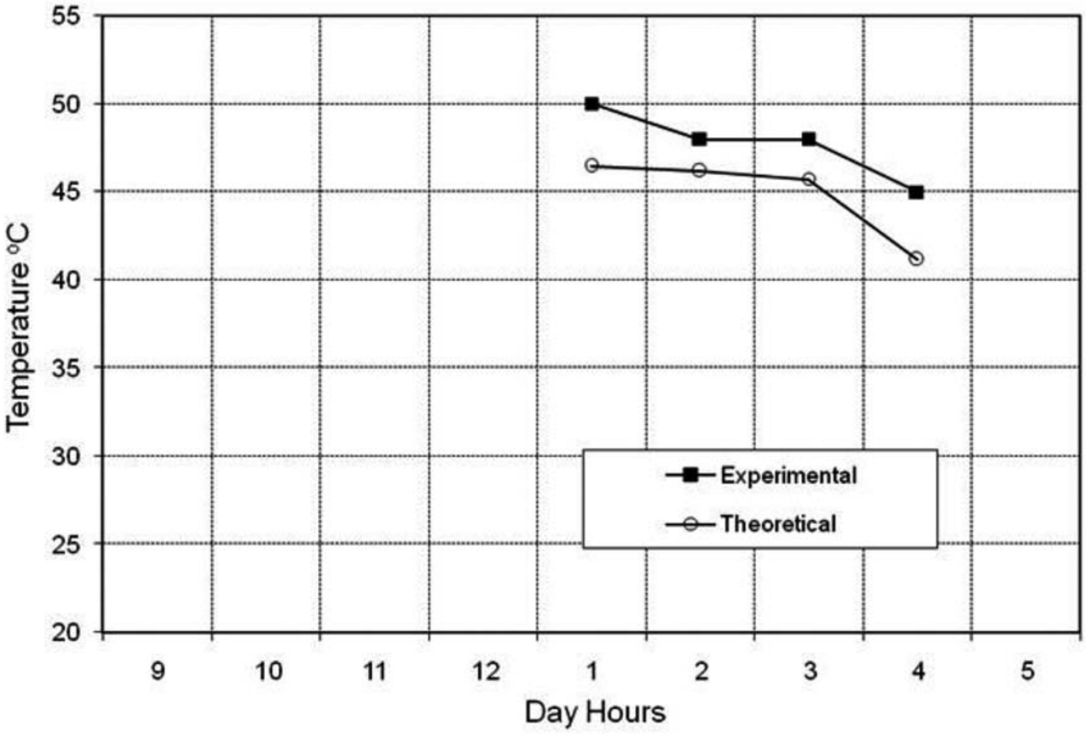

Fig. 9. Inner glass temperatures for passive solar still.

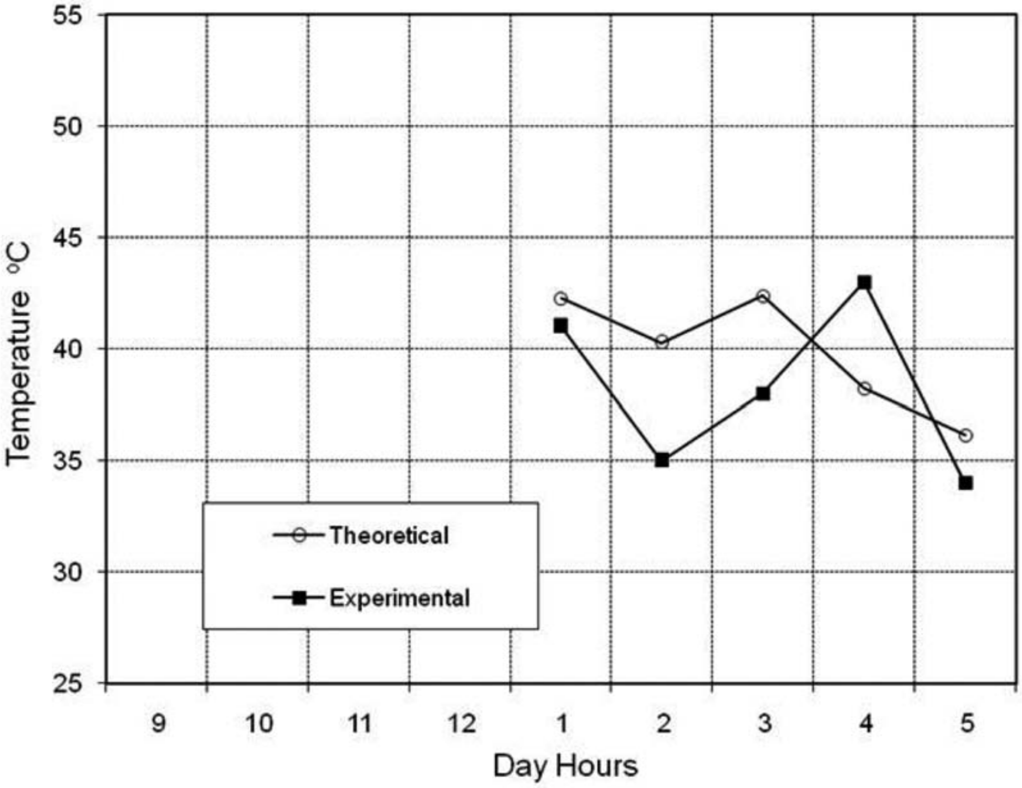

Fig. 10. Inner glass temperatures for active solar still without sun tracking.

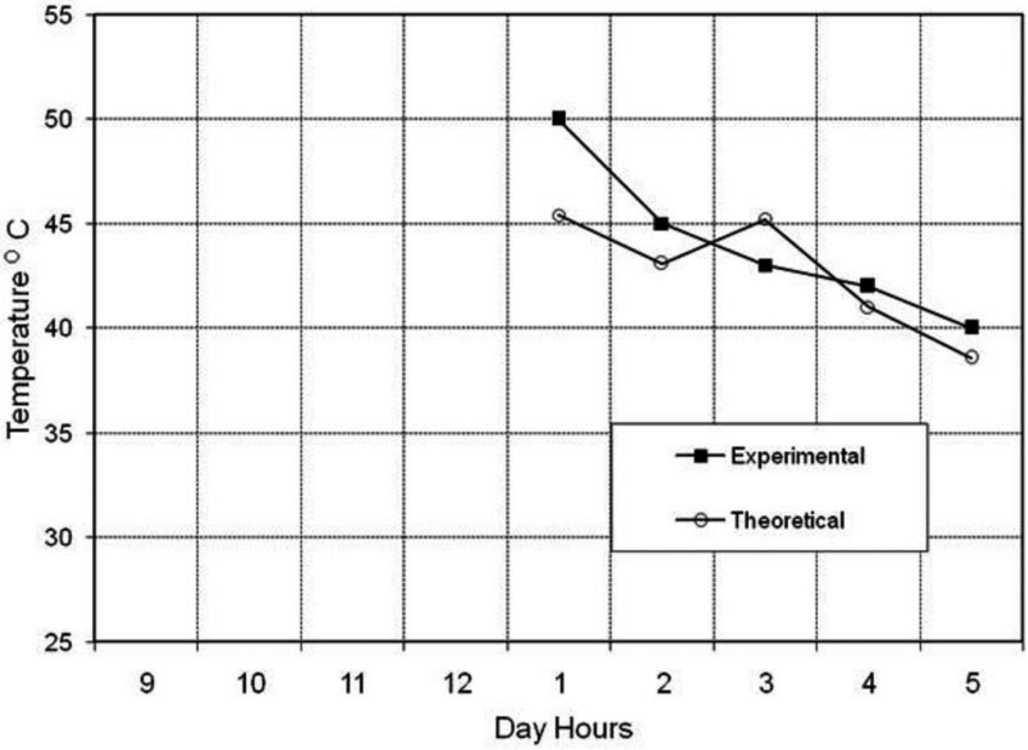

Fig. 11. Inner glass temperatures for active solar still with sun tracking.

radiation for Kuching town in Sarawak, Malaysia, and the Research & Development Unit from Central Mechanical Workshop (CMW) of Jabatan Kerja Raya Sarawak, for kindly lending us the PV solar panel, regulator and the battery.

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